TESTS OF A
BOUCHEROT INDUCTION MOTOR

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ARMOUR INSTITUTE OF TECHNOLOGY

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Comparative tests of a
 boucherot induction motor

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COMPARATIVE TESTS OF A BOUCHEROT INDUCTION MOTOR.

A THESIS

PRESENTED BY

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COMPARATIVE TESTS OF A BOUCHEROT INDUCTION MOTOR.

The Boucherot induction motor was designed primarily to minimize the difficulties encountered in starting up large polyphase induction motors under load. By M.Boucherot's method,this is accomplished by merely closing a switch. His motor is constructed exactly like any other polyphase induction motor of the squirrel-cage type,with the one exception that it has, instead of one squirrel-cage winding,two or more. As a general rule,only two windings are necessary. One of these,the outer,is for the purpose of producing a high torque at starting,while the other,the inner,is active during operation.

In order that the windings may possess these characteristics,the outer one is designed to have a high resistance and a low reactance,while the inner one has a low resistance and a high reactance. Therefore at starting,when the slip is great,the low reactance winding will carry practically all of the current, and,due to its high resistance,will produce a maximum torque. On the other hand,when the machine is up to speed,the frequency of the current in the rotor is low

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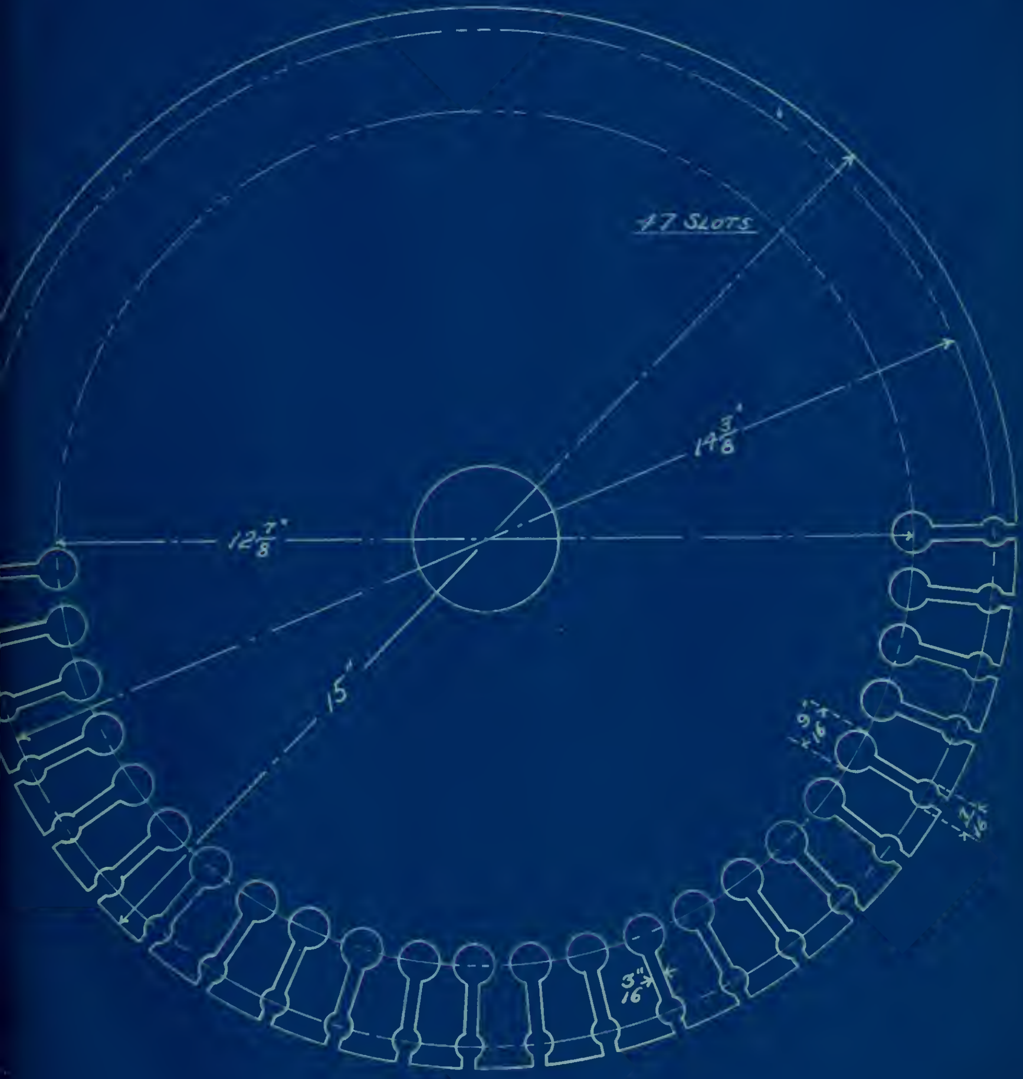
and hence the high reactance, low resistance winding becomes operative.

The object of this work was to investigate these characteristics in a Boucherot induction motor designed and built by R.L.Gray and R.Hay of the Class of 1911, Armour Institute of Technology. Their efforts were confined entirely to the rotor—the stator used being that of a standard 10 H.P., 25 cycle, 3-phase, 80 volt, G.E. induction motor. This rotor consists of iron laminations mounted directly on the shaft and held in place by two cast iron flanges. The positions of the windings on the rotor are shown in Fig.1. The outer winding consists of 0.4 inch copper rods and the inner one of 0.5 inch copper rods, bolted into cast iron and brass end rings respectively. Figure 2. shows the manner in which these rods are bolted into the end rings.

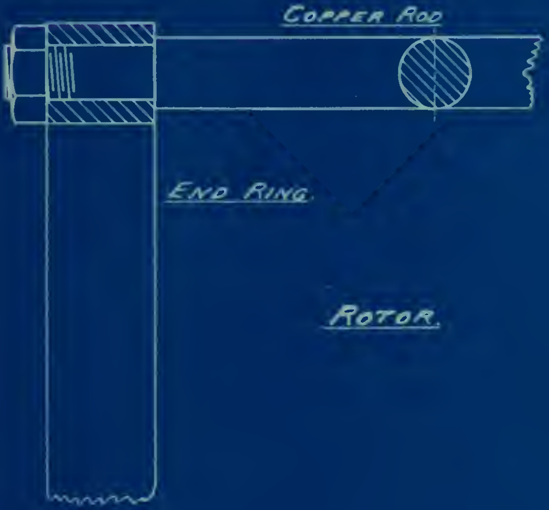
The purpose of placing the two windings on the same rotor was to produce a motor that had the desired starting characteristics of a high resistance motor together with the running characteristics of a low resistance motor. Theoretically the torques exerted by the two windings are additive so that the resultant torque at any speed whatsoever would be greater than that of either of the two windings alone. Figure 3.shows the

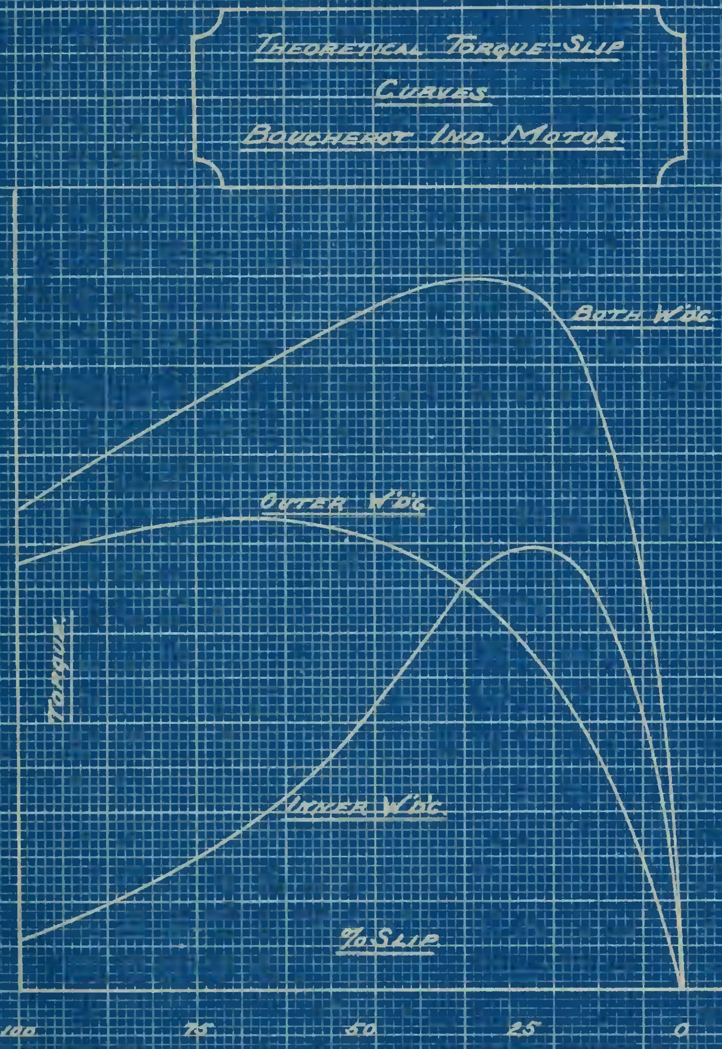
STAMPINGS FOR 10 HP. BOUCHEROT TYPE INDUCTION MOTOR.



SCALE 6"–1'

SKETCH SHOWING METHOD OF BOLTING ROTOR BARS TO END RINGS.





THEORETICAL TORQUE-SLIP CURVES BOUCHEROT IND. MOTOR

FIG 3.

torque-slip curves for the inner,outer,and both windings placed on the same rotor. From these curves it is evident that the high resistance winding exerts a maximum torque when the machine is at a standstill,whereas,the low resistance winding exerts a minimum torque at that time. Near to synchronous speed,however,the low resistance winding exerts a maximum torque and the high resistance winding a minimum. The resultant curve shows that the combined effects of the two windings is to produce a nearly uniform torque for all speeds.

This type of motor can be operated efficiency because of the automatic change of current from the high resistance winding to the low resistance winding while the speed is varying. The current in either of the windings depends upon the impedance of the circuit, which is effected by the frequency of the flux in the rotor. Thus,if one of the windings has a high inductive reactance,even though it has a low resistance,it will carry practically no current at the lower speeds. Conversely,the winding of low reactance and high resistance will carry almost all of the high frequency current as long as the impedance is lower than that of the low resistance circuit. Thus it will be sean that the resistances and reactances of the two circuits can be

so chosen that the one with the high resistance will have a low impedance when the frequency of the rotor currents is high and high impedance,comparatively,when the frequency of the rotor currents is very low. The low resistance circuit will have reciprocal properties , i.e.high impedance at start and low when running.

METHOD OF TESTS.

The Boucherot induction motor under consideration was subjected to a number of tests for the purpose of analyzing its characteristics. Among the important points to be noted were values of torque,slip,current consumption,power factor,and efficiency,for the outer and inner squirrel-cage windings separately,as well as for the combination of the two on the same rotor. In order that these tests be comparative a 10 H.P.25 cycle, 3-phase,80 volt G.E. induction motor was also experimented upon.

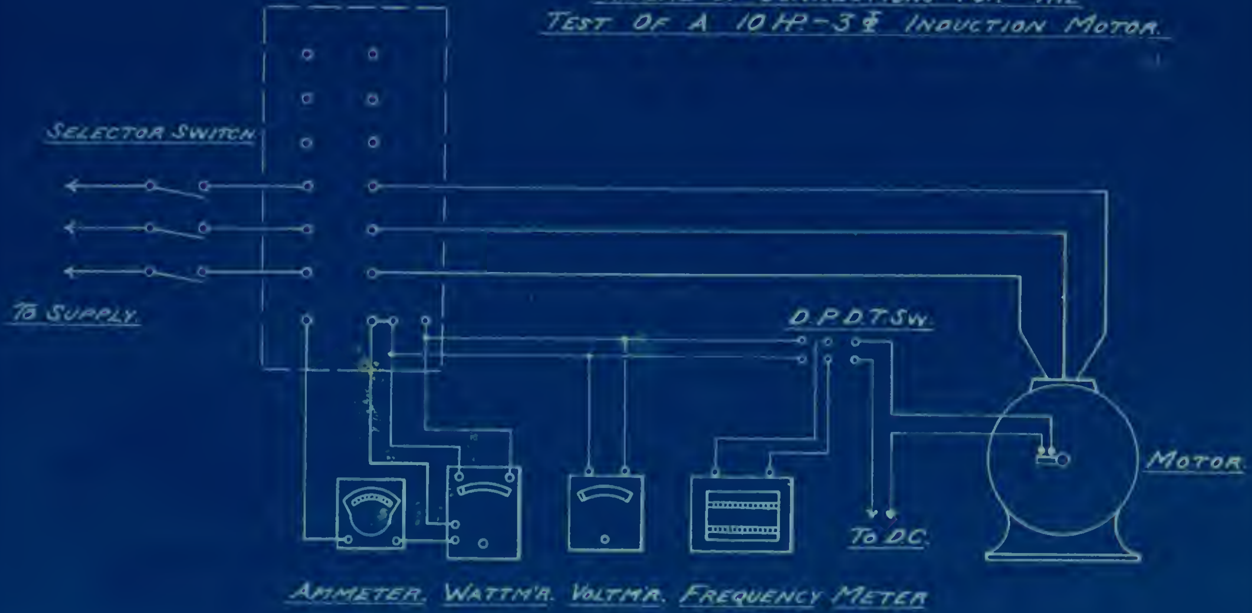
The method employed to obtain the above values was the Prony brake method by which the motor was loaded up to various degrees of output. This Prony brake was mounted on a pulley wheel,which was keyed to the rotor shaft,so that its arm rested upon a strut placed on a platform scale. As the speed of the motor was an important factor in determining the slip and the output, it was decided to measure it by using a frequency meter in conjunction with a segmented commutator attached to the rotor shaft. This commutator was electrically connected in series with the frequency meter so that the interruptions of the current,due to the rotation of the

commutator,were proportional to the speed.

The electrical connections to the motor are shown in Fig.4. Use is made of what is termed a selector switch so that the current in each line,the voltage between lines,and the true power supplied to the motor can be measured with but one ammeter,voltmeter,and wattmeter. The two wattmeter method of measuring power in a three phase circuit was used,the current coil of the wattmeter being placed in each of the two outside lines successively,and the pressure coil between the line with the current coil in it and the middle wire. The frequency meter which was used to measure the rotor speed was also employed to measure the line frequency-a two pole, double throw switch being used to change the frequency meter from one circuit to the other.

Three phase power was supplied to the motor at 25 cycles and 80 volts. The motor was run for a period of five minutes with full load current flowing through the stator in order that the results of the tests would not be seriously effected by error due to temperature rise. After the motor had obtained a fairly constant temperature,the load test was begun,the initial value of load being that when the Prony brake rested loosely upon the pulley wheel. As soon as the motor was operat-

SCHEME OF CONNECTIONS FOR THE TEST OF A 10 HP.–3Φ INDUCTION MOTOR.



ing at constant speed under a definite load,and the voltage and line frequancy adjusted to normal values,the current in two lines,the true power input,and the speed of the rotor,were noted. The load was varied from the initial value to twenty-five percent overload in equal steps. Witheach change of load,the line voltage was readjusted to normal value since the copper drop in the leads with increasing current caused the applied voltage to decrease. The line frequency had to be adjusted also because of the decrease of speed of the alternator due to increase of electrical load. Before reading any of the instruments,the motor was allowed to run under the particular value of load until the speed and the current consumption had become fairly constant. The line voltage was always measured in the same phase and with the ammeter and wattmeter out of circuit so that the chances of error were minimized. Numerous load runs were made on the Boucherot motor with the outer,the inner,and both windings in place. Several load runs were also made on the G.E. motor. After every series of load runs,the Prony brake was removed from the motor and placed on an accurately balanced pulley wheel for the purpose of determining its tare weight.

No load runs were made on each rotor for the purpose of determining friction and windage losses and also in order to compare the watts input to the motor at different voltages. The electrical connections to the motor were the same as those used for the load run with the exception that no readings were taken of the frequency meter in circuit with the segmented commutator. The applied voltage per phase was varied from 20 volts to 85 volts in increments of 5 volts,the line frequency being kept constant at 25 cycles. Readings of power input and current consumption were taken. For these no load runs,the power factor was less than 50 percent so that one of the two wattmeter readings was negative,and hence due care was exercised in reading and tabulating these values. As before,the line voltage was always read in the same phase and with the ammeter and wattmeter out of circuit.

Blocked rotor runs were made for the purpose of plotting circle diagrams. The connections were the same as shown in Fig.4.and,as the motor was kept at a standstill,the frequency meter was used only to measure the line frequency. The rotor was blocked by tightening the Prony brake on the pulley wheel so that it could not revolve. Low values of voltage were applied to the stator

winding and the line current and power supplied were measured. The scale was balanced for the different voltages,so that a measure of the starting torque could be had. The voltage impressed was increased from a low value to that value which caused a current of 225 per cent of normal value to flow through the stator. This was for the purpose of obtaining data more nearly in accord with what actually takes place in the motor.

The resistance of the stator was measured since it was necessary for the calculation of the data used for drawing the circle diagrams. A direct current of about 75 percent of normal value was sent through the stator and the drop between terminals was measured with a low reading voltmeter. Several readings were taken.

The instruments used in the tests were calibrated and each was found accurate to within one per cent. This degree of accuracy was sufficient,since the errors involved in tests in which the Prony brake is used do not warrant a better degree.

Several difficulties were encountered in making these tests,all of which had the tendency to vitiate the results. The method of measuring the rotor speed was perhaps as good as could be found but the error involved in reading the frequency meter when

several reeds were vibrating with different amplitudes, was considerable. The rotor speed was checked with a Horn tachometer with fair success. There is also introduced into the tests an error due to the variation of load from that recorded from the brake scale setting, as it was, in most cases, impossible to keep the scale arm in a balanced position while the instruments were being read. The line current could not be read with very great accuracy because of the fact that the needle of the ammeter oscillated back and forth over several scale divisions. A very slight error in the impressed voltage was caused by the variation of the copper drop in the leads with the fluctuations of current. The change of stator resistance with increase of temperature was especially pronounced for the large values of current, and particularly in the blocked rotor runs.

One average set of results for each winding was made up from the data taken from all the tests. This average set included current consumption, rotor speed, and power input at each value of output for the load tests, and current consumption and power input, for each value of voltage for the no load and blocked rotor tests. From this data the apparent power input, horse power output, percent slip, power factor, torque, and efficiency were calculated.

LOG OF TESTS MADE ON A 10 H.P. G.E. INDUCTION MOTOR.

80 VOLTS 3-PHASE 25 CYCLES 4 POLES

Net Load Pounds	Current Amperes	Input K.W.	Speed R.P.M.	Output H.P.	Output K.W.	Efficiency %
7.8	35.5	2.50	748	2.22	1.58	66.2
8.2	35.7	2.45	748	2.34	1.75	71.2
13.2	40.4	3.69	744	3.74	2.79	75.6
17.2	45.1	4.45	738	4.85	3.62	81.4
21.2	50.4	5.38	735	5.94	4.43	82.4
25.2	55.6	6.23	733	7.04	5.25	84.4
29.2	61.3	7.18	731	8.13	6.06	84.5
33.2	69.3	8.03	730	9.24	6.89	85.9
37.2	74.1	9.05	728	10.32	7.70	85.3
41.2	81.4	9.91	725	11.35	8.47	85.4
45.2	88.7	10.83	719	12.35	9.22	85.0
49.2	96.0	11.81	716	13.41	10.00	84.7
53.2	103.0	13.08	712	14.40	10.70	82.3

Net Load Pounds	Slip R.P.M.	% Slip %	Apparent Watts K.W.	P. F. %	Torque Lbs-Ft.
7.8	2	0.27	4.92	50.9	15.6
8.2	2	0.27	4.95	49.5	16.4
13.2	6	0.80	5.60	65.9	26.4
17.2	12	1.60	6.26	71.0	34.4
21.2	15	2.00	6.99	77.0	42.4
25.2	17	2.27	7.72	80.7	50.4
29.2	19	2.54	8.50	84.5	58.4
33.2	20	2.67	9.60	83.6	66.4
37.2	22	2.95	10.29	88.0	74.4
41.2	25	3.33	11.28	88.0	82.4
45.2	31	4.14	12.30	88.0	90.4
49.2	34	4.54	13.31	88.7	98.4
53.2	38	5.07	14.30	91.4	106.4

LOG OF TESTS MADE ON A 10 H. P. G. E. INDUCTION MOTOR.

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25 CYCLES 3-PHASE 4 POLES

NO LOAD RUN.

Volts	Current	Input K.W.
20	8.5	0.120
25	9.8	0.141
30	11.5	0.169
35	13.0	0.207
40	15.1	0.240
45	16.9	0.277
50	18.8	0.319
55	20.8	0.361
60	22.6	0.415
65	24.6	0.475
70	26.6	0.541
75	28.9	0.618
80	31.2	0.632
85	33.6	0.733

BLOCKED ROTOR VALUES.

Volts	Current	Input K.W.
2.00	12.90	0.04
3.90	26.55	0.16
5.60	38.10	0.25
8.30	56.50	0.55
9.70	65.75	0.78
11.90	82.00	1.25
14.80	99.00	1.87
18.75	126.00	2.90
26.50	176.00	6.10

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LOG OF TESTS MADE ON A 10 H.P. BOUCHEROT INDUCTION MOTOR.

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80 VOLTS 25 CYCLES 3-PHASE 4 POLES

Net Load Pounds	Current Amperes	Input K.W.	Speed R.P.M.	Output K.W.	Output H.P.	Efficiency %
6.5	28.7	2.26	743	1.37	1.84	60.7
8.5	30.5	2.42	741	1.79	2.40	74.0
12.0	35.9	3.53	730	2.44	3.34	70.5
14.0	38.1	3.83	725	2.88	3.86	75.3
18.0	44.1	4.70	717	3.67	4.92	78.2
22.0	50.1	5.71	707	4.42	5.92	77.5
26.0	57.8	6.56	697	5.15	6.90	78.5
30.0	64.5	7.45	688	5.86	7.86	78.6
34.0	71.0	8.57	677	6.52	8.75	76.1
38.0	79.0	9.53	673	7.25	9.73	76.1
42.0	85.6	10.58	660	7.88	10.58	74.6
46.0	92.0	11.58	652	8.51	11.41	73.6
50.0	104.8	13.00	623	8.86	11.90	68.2

Net Load Pounds	Slip R.P.M.	% Slip %	Apparent Input K.W.	P. F. %	Torque Lbs-Ft.
6.5	7	.93	3.97	56.9	13
8.5	9	1.20	4.22	57.3	17
12.0	20	2.67	4.96	71.1	24
14.0	25	3.33	5.27	72.7	28
18.0	33	4.40	6.10	77.0	36
22.0	43	5.47	6.94	82.5	44
26.0	53	7.07	8.00	82.1	52
30.0	62	8.25	8.94	83.5	60
34.0	73	9.73	9.84	87.3	68
38.0	77	10.30	10.92	87.2	76
42.0	90	12.00	11.88	89.4	84
46.0	98	13.10	12.72	90.9	92
50.0	127	16.90	14.50	89.8	100

LOG OF TESTS MADE ON A 10 H.P. BOUCHEROT INDUCTION MOTOR.

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25 CYCLES 3-PHASE 4 POLES

NO LOAD RUN.

Volts	Current	Input K.W.
20	7.3	0.15
25	8.8	0.18
30	9.4	0.21
35	10.6	0.26
40	11.8	0.29
45	13.1	0.36
50	14.5	0.41
55	15.9	0.48
60	17.2	0.58
65	18.6	0.65
70	20.1	0.76
75	21.7	0.88
80	23.6	0.98
85	25.5	1.10

BLOCKED ROTOR VALUES.

Volts	Current	Input K.W.
18.00	50.5	0.93
18.25	56.8	1.13

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LOG OF TESTS MADE ON BOUCHEROT ROTOR WITH INNER WINDING ONLY.

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80 VOLTS 25 CYCLES 3-PHASE 4 POLES

Net Load Pounds	Current Amperes	Input K.W.	Speed R.P.M.	Output H.P.	Output K.W.	Efficiency %
6.7	27.0	2.35	743	1.87	1.39	57.2
10.7	31.8	3.25	734	3.00	2.23	68.5
14.7	36.6	4.05	728	4.08	3.04	75.0
18.7	42.3	5.03	720	5.13	3.82	75.8
22.7	48.7	5.91	711	6.29	4.58	77.5
26.7	55.0	6.88	702	7.14	5.32	77.2
30.7	61.6	7.82	694	8.12	6.05	77.3
34.7	67.5	8.94	686	9.00	6.70	75.0
38.7	74.5	9.90	677	9.98	7.43	75.0
42.7	83.2	11.03	664	10.80	8.03	72.7
46.7	88.5	12.09	654	11.64	8.67	71.8
50.7	97.3	13.14	639	12.35	9.20	70.0

Net Load Pounds	Slip R.P.M.	% Slip %	Apparent Input K.W.	P. F. %	Torque Lbs-Ft.
6.7	7	0.93	3.74	62.8	13.4
10.7	16	2.13	4.42	73.3	21.4
14.7	22	2.90	5.08	79.7	29.4
18.7	30	4.00	5.87	85.9	37.4
22.7	39	5.20	6.75	87.7	45.4
26.7	48	6.30	7.62	90.5	53.4
30.7	56	7.50	8.53	91.6	61.4
34.7	64	8.50	9.35	95.6	69.4
38.7	73	9.70	10.32	95.8	77.4
42.7	86	11.50	11.52	95.6	85.4
46.7	96	12.80	12.25	98.5	93.4
50.7	111	14.80	13.49	97.4	101.4

LOG OF TESTS MADE ON BOUCHEROT ROTOR WITH INNER WINDING ONLY.

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25 CYCLES 3-PHASE 4 POLES

NO LOAD RUN.

Volts.	Current.	Input K.W.
23.5	7.50	0.160
25.0	8.30	0.197
30.0	9.50	0.223
35.0	10.70	0.263
40.0	11.85	0.322
45.0	13.15	0.367
50.0	14.35	0.416
55.0	15.65	0.480
60.0	17.15	0.550
65.0	18.80	0.645
70.0	20.05	0.720
75.0	21.80	0.825
80.0	23.65	0.940
85.0	25.80	1.065

BLOCKED ROTOR VALUES.

Volts.	Current.	Input K.W.
24.5	96.7	3.350
37.8	145.0	8.180

LOG OF TESTS MADE ON BOUCHEROT ROTOR WITH OUTER WINDING ONLY.

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80 VOLTS 25 CYCLES 3-PHASE 4 POLES

Net Load	Current	Input	Speed	Output	Output	Efficiency
Pounds	Amperes	K.W.	R.P.M.	H. P.	K.W.	%
7.4	32.3	2.59	610	1.72	1.28	49.4
11.8	41.0	3.86	508	2.28	1.70	44.0
13.8	45.1	4.40	457	2.40	1.79	40.7
15.8	47.2	4.79	410	2.47	1.84	38.5
17.8	51.8	5.36	375	2.54	1.89	35.4
19.8	55.0	5.85	325	2.45	1.83	31.3
21.8	59.0	6.35	248	2.06	1.54	24.3
23.8	61.8	6.88	225	2.04	1.52	22.1
25.8	64.8	7.42	200	1.97	1.47	19.8
27.8	68.5	7.95	175	1.85	1.38	17.4

Net Load	Slip	% Slip	Apparent Watts	P. F.	Torque
Pounds	R.P.M.	%	K.W.	%	Lbs-Ft.
7.4	140	18.6	4.43	58.5	14.8
11.8	242	32.2	5.48	70.4	23.6
13.8	293	39.1	6.00	73.4	27.6
15.8	340	45.3	6.36	75.2	31.6
17.8	425	56.5	7.06	75.9	35.6
19.8	475	63.3	7.48	78.2	39.6
21.8	502	66.8	8.02	79.1	43.6
23.8	525	70.0	8.56	80.3	47.6
25.8	550	73.2	8.98	82.5	51.6
27.8	575	76.6	9.50	83.7	55.6

LOG OF TESTS MADE ON BOUCHEROT ROTOR WITH OUTER WINDING ONLY.

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25 CYCLES 3-PHASE 4 POLES

NO LOAD RUN.

Volts	Current	Input K.W.
15	11.5	0.23
20	11.8	0.28
25	12.0	0.34
30	12.0	0.39
35	12.8	0.45
40	13.7	0.51
45	14.7	0.60
50	15.7	0.59
55	16.8	0.67
60	18.1	0.74
65	19.5	0.89
70	21.2	0.93
75	22.9	1.04
80	24.4	1.12
85	26.7	1.23
90	29.3	1.37
95		

BLOCKED ROTOR RUN.

Volts	Current	Input K.W.
56.8	53.0	4.35
59.2	57.0	5.08
60.5	55.0	5.05
64.5	61.1	5.95
67.8	68.0	6.90
70.3	68.0	7.10
74.3	78.0	8.70
74.5	75.0	8.45
80.0	83.0	10.30

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SAMPLE CALCULATIONS.

Test made on Boucherot rotor with inner winding only.

Data for load test:

80 Volts 25 Cycles 3-Phase 4 Poles.

Net load	Current	Input	Speed
42.7 lb.	83.2amp	11.03kw	664rpm

OUTPUT $= 2\pi RNP \div 33{,}000.$ H.P.

R 2ft.
N 664
P 42.7

OUTPUT $= 2\pi\, 2\times 664\times 42.7\div 33{,}000 = 10.80$ H.P.

$= 10.80\times .746 = 8.03$ K.W.

EFFICIENCY = Output ÷ Input

$= 8.03\div 11.03 = 72.77\%$

APPARENT INPUT $= 1.73EI$

$= 1.73\times 80\times 83.2 = 11.52$ K.W.

POWER FACTOR = Actual power ÷ Apparent power

$= 11.03\div 11.52 = 95.6\%$

PERCENT SLIP = Syn.speed-Rotor speed ÷ Syn.speed

$= 750-664\div 750 = 11.5\%$

Data for circle diagrams.

RESISTANCE of STATOR — .0329 ohms per phase

No load run.

80 volts 23.65 amp. 940 watts 25 cycles

APPARENT POWER = 1.73 × 80 × 23.65 = 3280 watts

POWER FACTOR = 940+3280 = 28.7%

WATTLESS FACTOR – 95.8%

POWER CURRENT = 0.287 × 23.65 = 6.80 amp.

WATTLESS CURRENT = 0.958 × 23.65 = 22.7 amp.

Blocked rotor run.

42.0 volts 161 amp. 10,150 watts 25 cycles

37.8 volts 145 amp. 8,180 watts 25 cycles

Calculated for 80 volts:

80.0 volts 307 amp. 36,750 watts 25 cycles

APPARENT POWER = 1.73 × 80 × 307 = 42,600 watts

POWER FACTOR = 36,750+42,600 = 86.3%

WATTLESS FACTOR 50.5%

POWER CURRENT = 0.863 × 307 = 265 amp.

WATTLESS CURRENT = 0.505 × 307 = 155 amp.

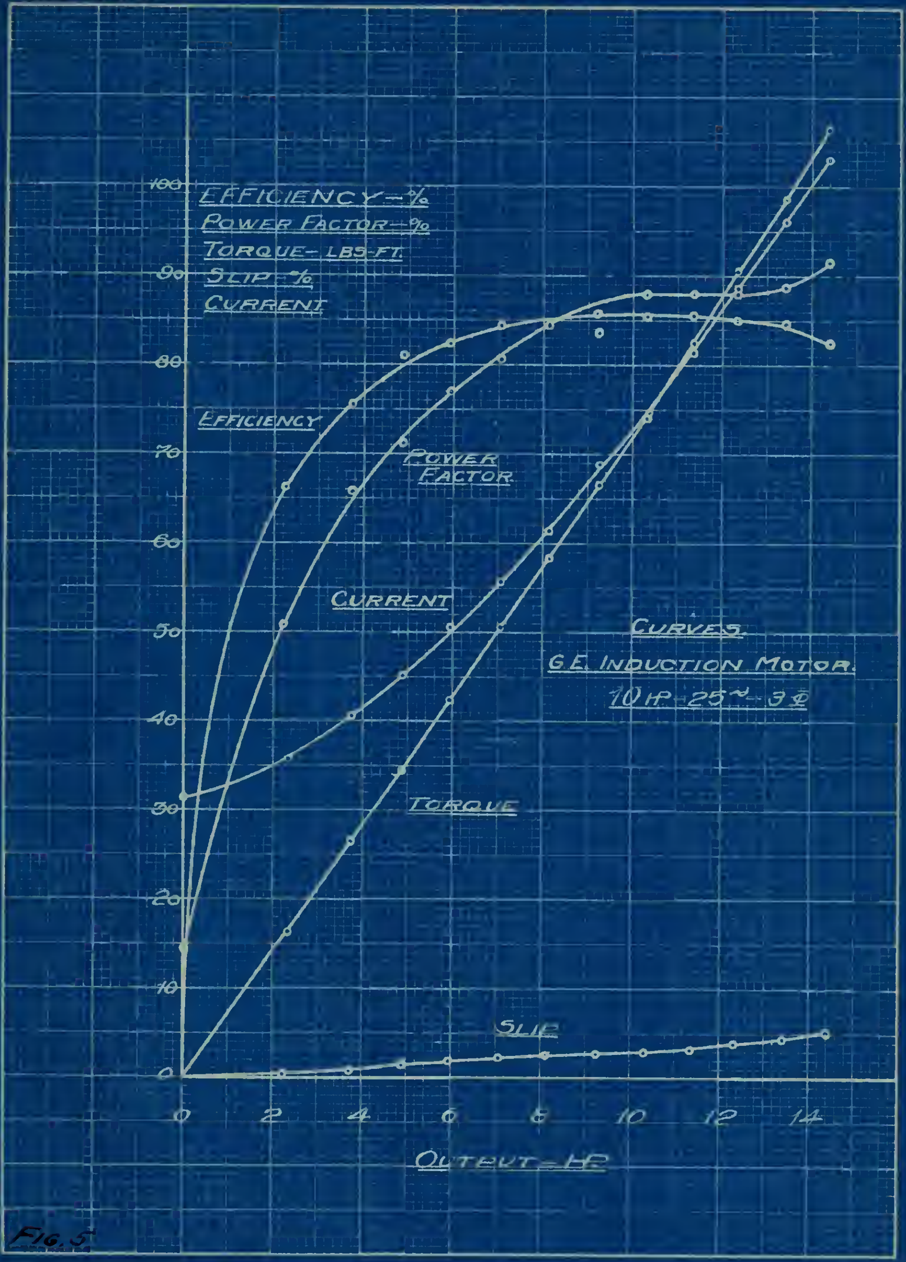
EFFICIENCY – %
POWER FACTOR – %
TORQUE – LBS-FT.
SLIP – %
CURRENT
100
90
80
70
60
50
40
30
20
10
0
EFFICIENCY
POWER FACTOR
CURRENT
TORQUE
SLIP
CURVES.
G.E. INDUCTION MOTOR.
10 H.P. – 25~ – 3Φ
0
2
4
6
8
10
12
14
OUTPUT – H.P.

FIG. 5

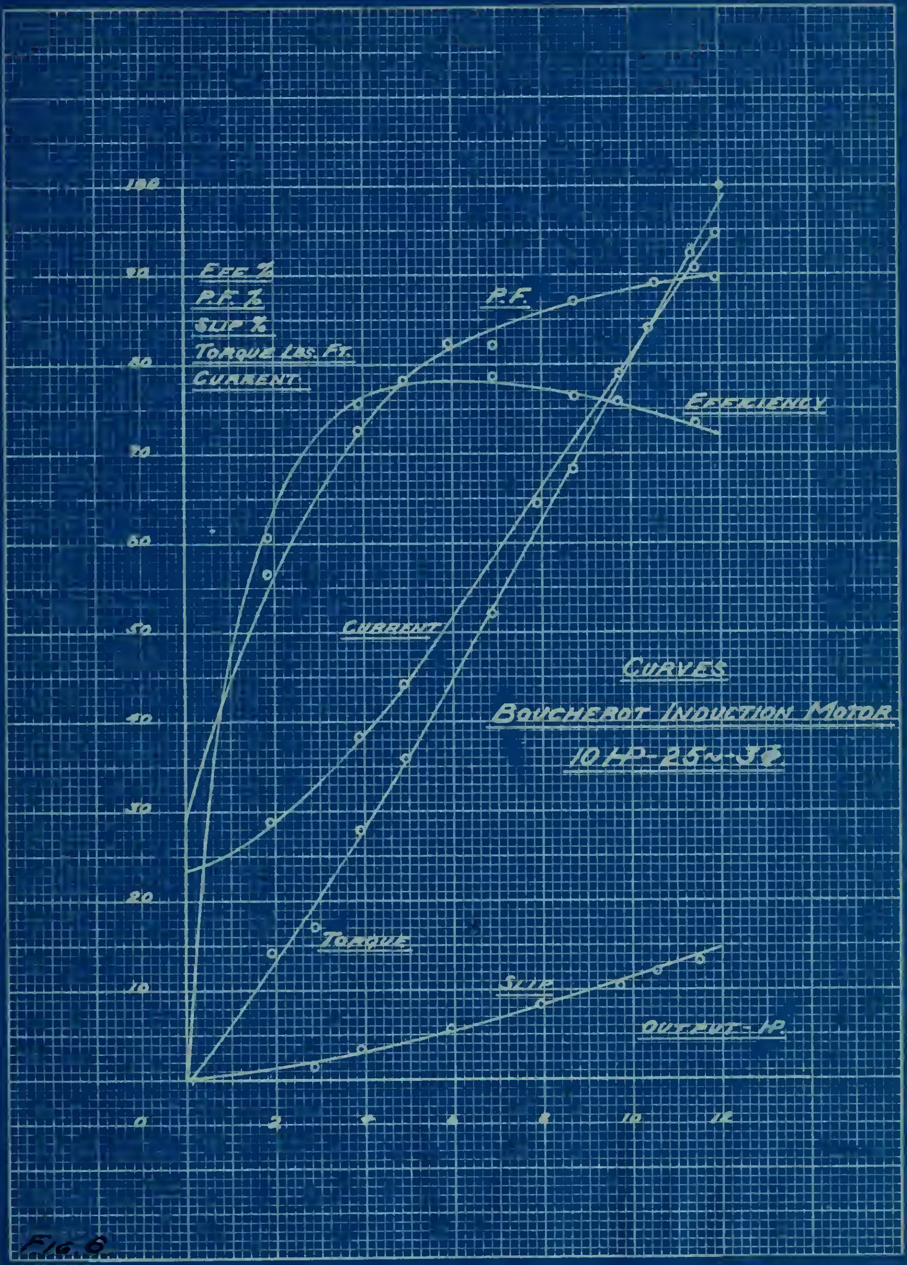

Curves
Boucherot Induction Motor
10 HP-25~-3φ
Eff %
P.F. %
Slip %
Torque Lbs. Ft.
Current
P.F.
Efficiency
Current
Torque
Slip
Output - HP.
100
90
80
70
60
50
40
30
20
10
0
2
4
6
8
10
12

Fig. 6

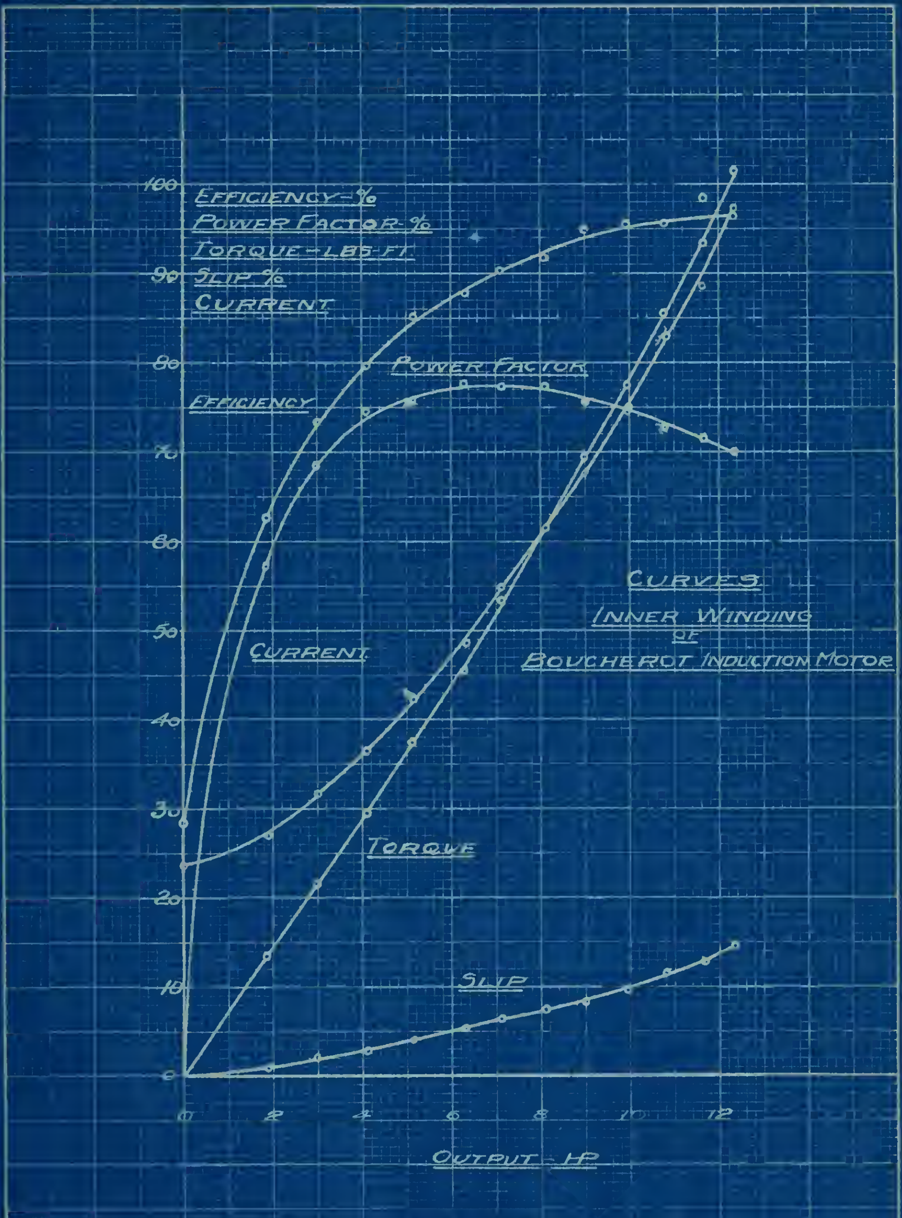
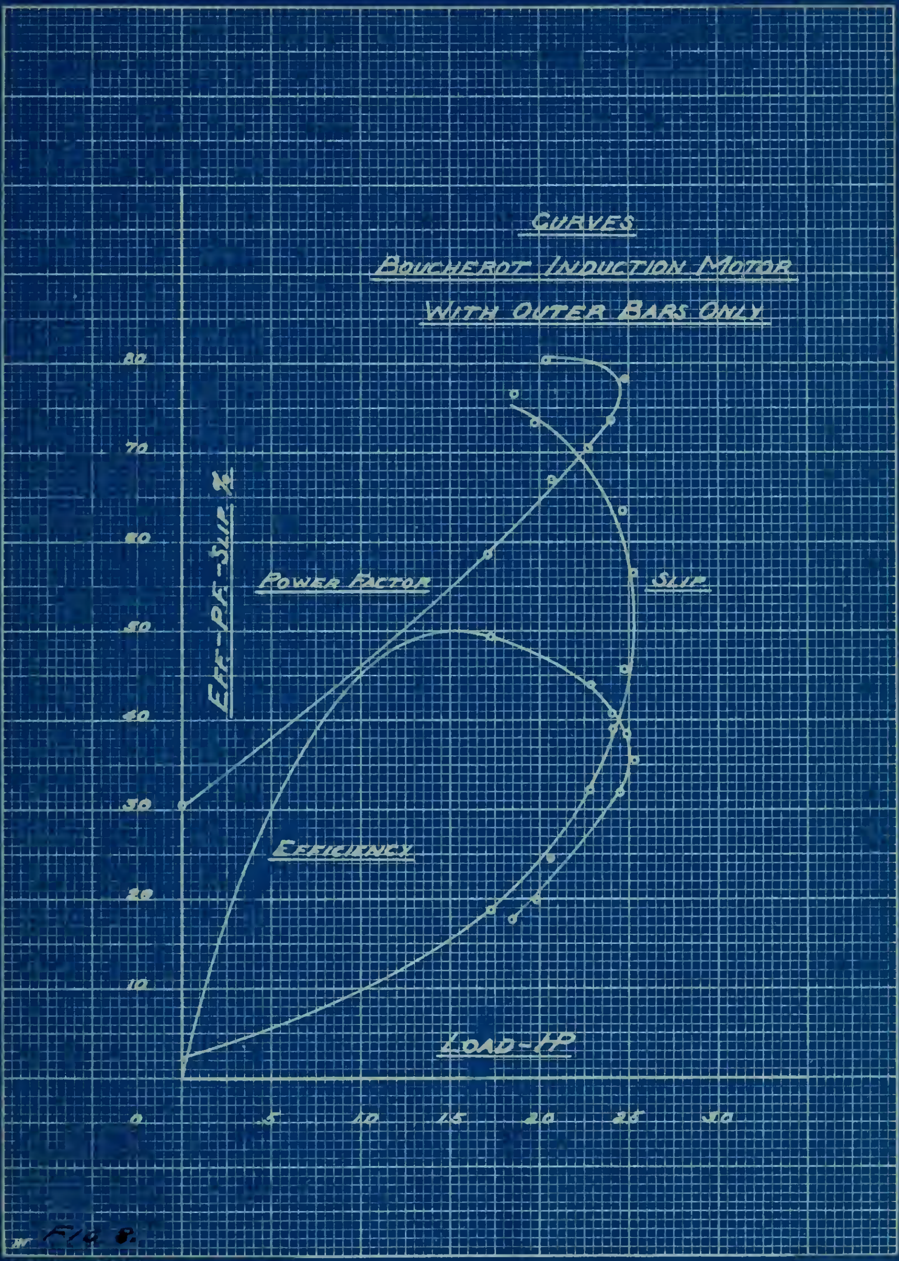

EFFICIENCY-%
POWER FACTOR-%
TORQUE-LBS-FT
SLIP %
CURRENT
100
90
80
70
60
50
40
30
20
10
0
POWER FACTOR
EFFICIENCY
CURRENT
TORQUE
SLIP
CURVES
INNER WINDING
OF
BOUCHEROT INDUCTION MOTOR
0
2
4
6
8
10
12
OUTPUT - HP

Fig 7



CURVES

BOUCHEROT INDUCTION MOTOR

WITH OUTER BARS ONLY

FIG. 8.

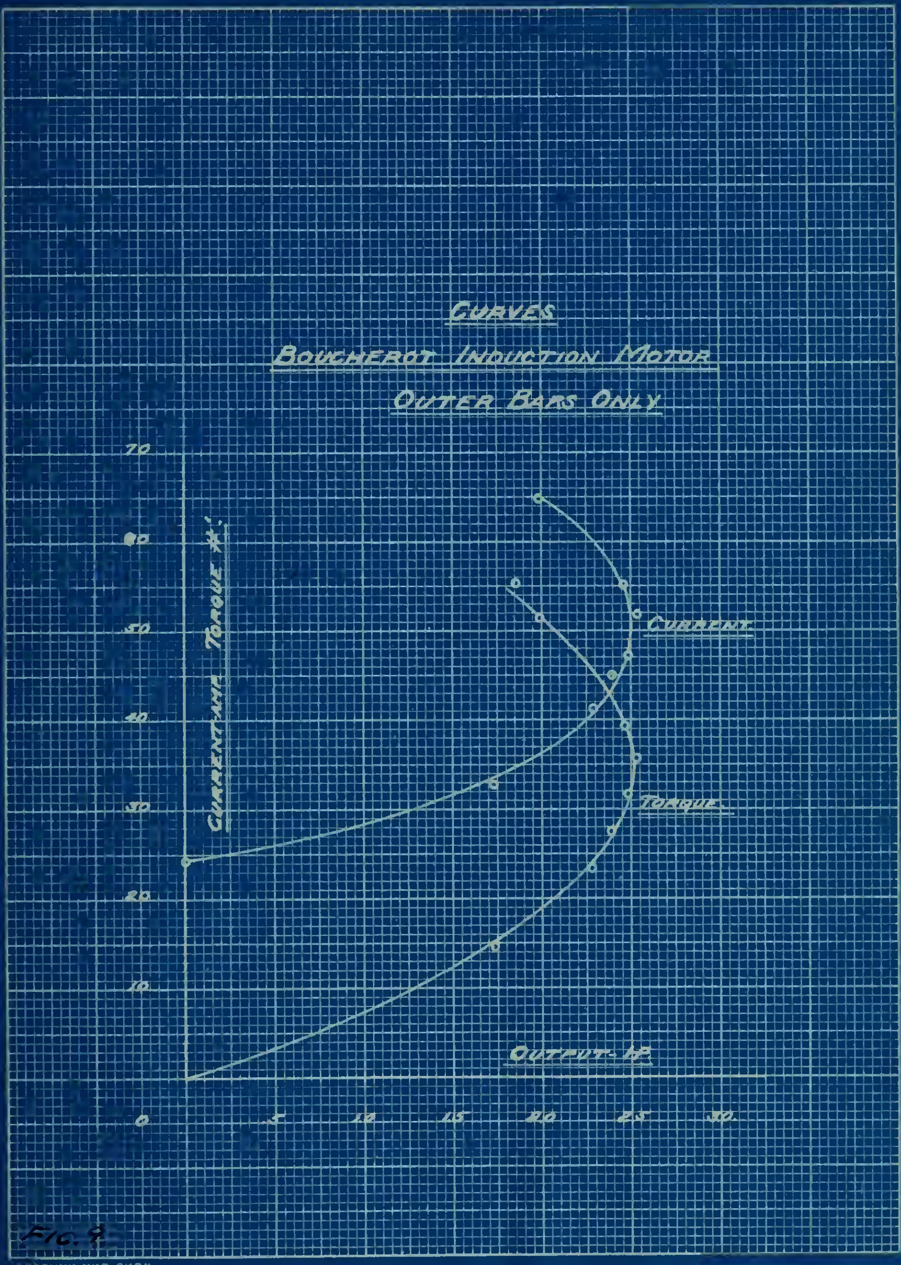


FIG. 9

FREEMAN AND SNOW

DISCUSSION OF RESULTS.

With the completion of the experimental work, the data was calculated in order to determine, as far as possible, the more important characteristics of each motor. The accompanying curves were then plotted with horse power output as abscissas and efficiency, power factor, per cent slip, line current consumption, and torque at pulley in pounds-feet as ordinates. Also a set of no load curves, with volts as abscissas and watts input as ordinates, were plotted.

These curves show several interesting features. As might be supposed, the G.E. motor gives the best efficiency, 85.8%, at the rated output of 10 H.P. The Boucherot motor, tested with both windings, has a maximum efficiency of 78% occurring at 6 H.P. and, tested with inner and outer windings separately, gives 77.5% at 6.5 H.P. and 50% at 1.5 H.P. respectively. That this last value of 50% at 1.5 H.P. should occur is self evident, for the outer winding, as stated before, is merely for starting purposes and accordingly has far too much resistance for running conditions. Also, it is reasonable that the inner winding and the two windings together should give practically the same values, since during

operation,the inner winding is the one in use. That the maximum efficiency occurs at about 6 H.P.,however,seems to indicate that the motor was overrated.

In respect to power factor,the G.E. motor reaches a maximum value of about 86% at 10 H.P. The Boucherot motor,with both windings,attains a power factor of 90% at 12 H.P.,while,with the outer and inner windings alone, 83.7% at 1.85 H.P. and 96% at 12 H.P. are reached. This latter value,which seemed extremely high,was verified by twice repeating the test. A power factor this high shows too low an inductance for the inner winding,which was just opposite to what was desired. A value of power factor more in the neighborhood of 85% would have given better results.

As for the per cent slip,here again the G.E. motor is preeminent,it having but 3% slip at rated output. The per cent slips for the Boucherot motor again show that its windings have too high a resistance. For 10 H.P. output,the two windings together,and the outer and inner ones separately,show slips of 11.5%,10%,and 100% respectively.

The no load curves were plotted with volts as abscissas and watts input as ordinates. As the run

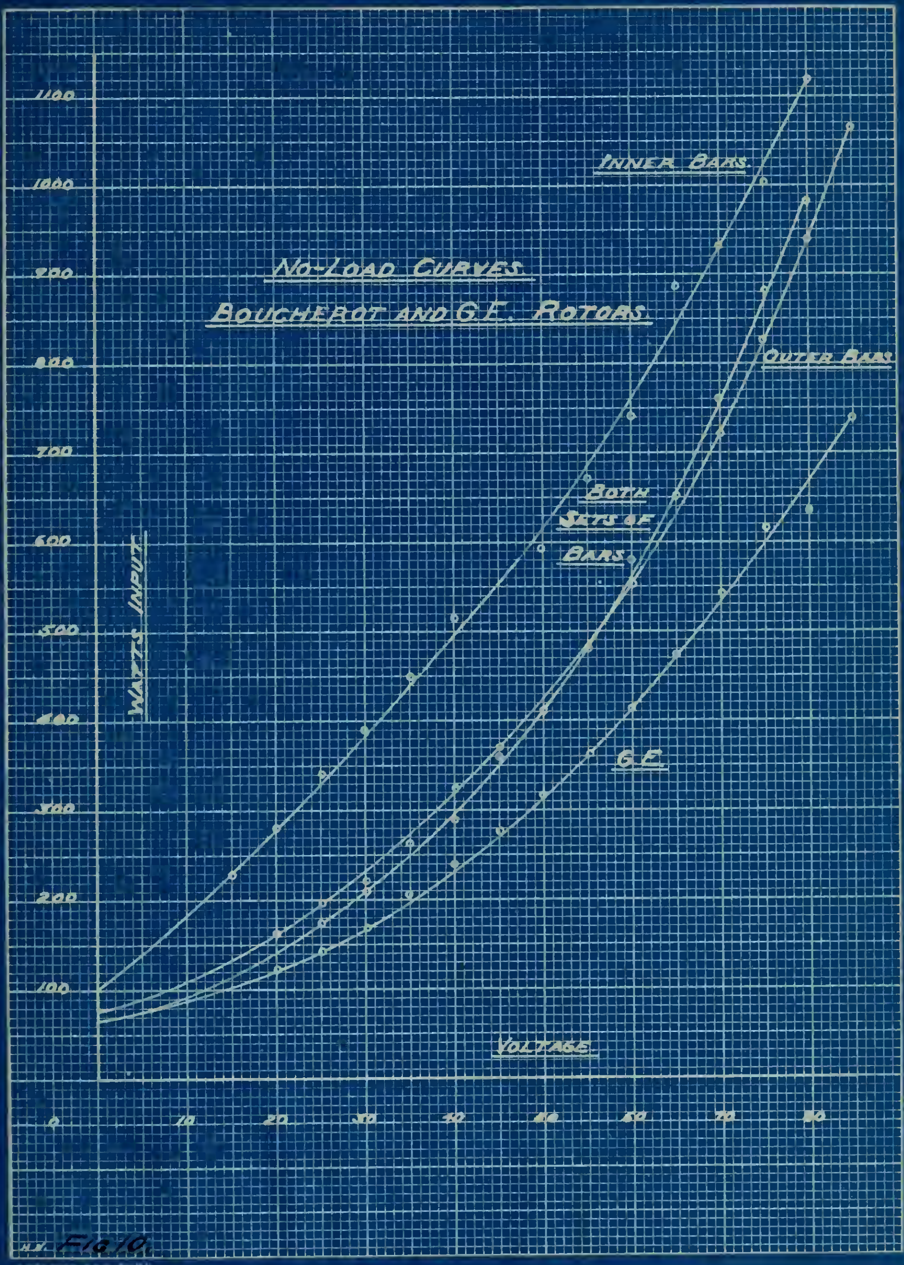
NO-LOAD CURVES
BOUCHEROT AND G.E. ROTORS
INNER BARS.
OUTER BARS
BOTH SETS OF BARS
G.E.
WATTS INPUT
VOLTAGE
1100
1000
900
800
700
600
500
400
300
200
100
0
10
20
30
40
50
60
70
80

FIG 10.

could not be continued to zero voltage,the curves were drawn to that value as indicated by the general direction. Since the iron and copper losses are zero at no voltage,the apparent input at that point gives only the friction and windage losses. The values obtained for the two rotors,about 70 watts,were practically equal,notwithstanding that the Boucherot weighed about twice that of the G.E.

The plate marked "Theoretical Torque-Slip Curves" indicates how the torque was to vary with the slip in each set of windings. The inner winding,being highly inductive,was designed to have a low starting and a high running torque. The outer winding,having a high resistance and low inductance,as explained previously,was to exert a maximum torque at starting and to decrease in value down to zero at synchronous speed. The rotor with both windings was then to contain the excellent features of each winding and give a high torque at both start and full load speed. Unfortunately,due to more resistance in each winding than was bargained for,the actual results came out as shown in Fig.11. From the curves it can be seen that the inner winding,which was to have an extremely low resistance,has just sufficient to make it an ex-

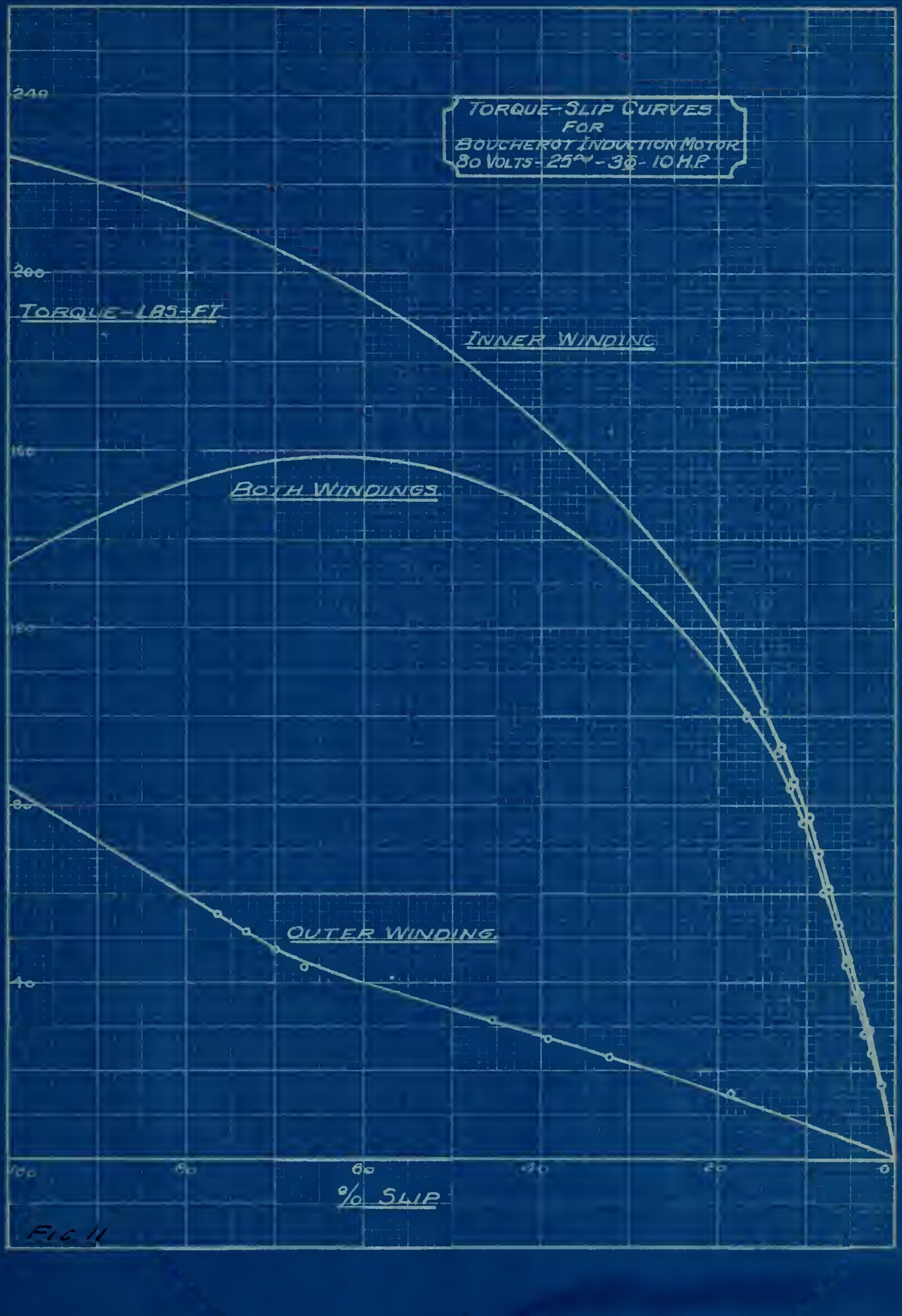

TORQUE–SLIP CURVES
FOR
BOUCHEROT INDUCTION MOTOR
80 VOLTS - 25~ - 3Φ - 10 H.P.
TORQUE–LBS–FT.
240
200
160
120
80
40
INNER WINDING
BOTH WINDINGS
OUTER WINDING
100
80
60
40
20
0
% SLIP

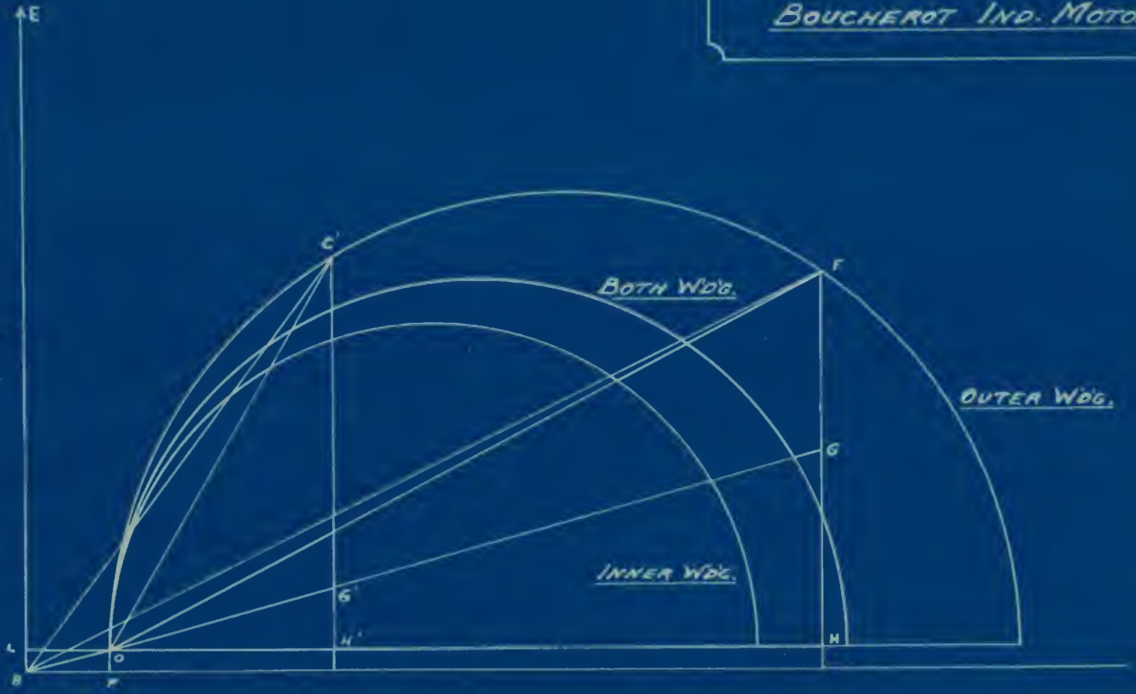
FIG. 11

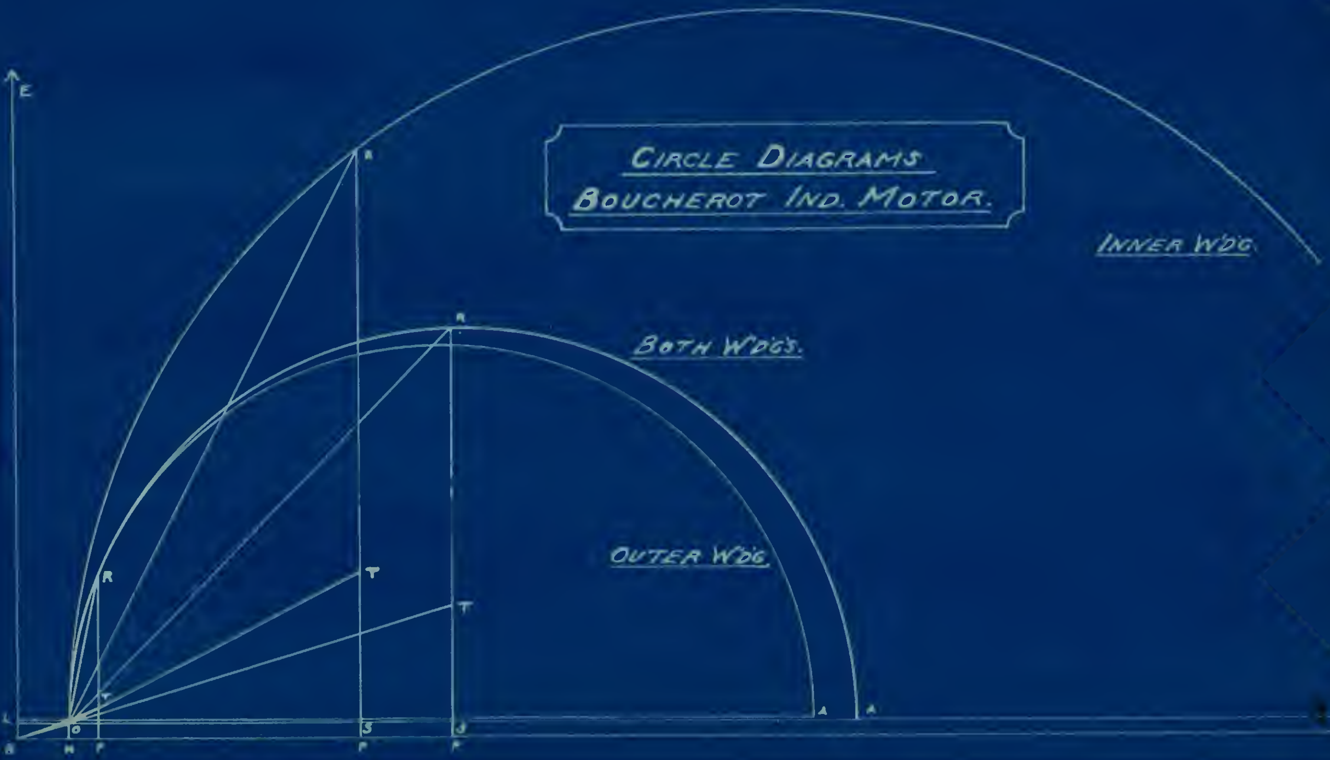
cellent starting winding. In the outer winding,the resistance is so very high that the torque at starting has a value to the right of the peak of the curve and therefore less than maximum torque for that winding. The relation between torque and slip,for both windings together,however,gives a curve which is approximately the difference between the other two curves,and is indicative of both good starting and running characteristics.

As the circle diagrams express simply and fairly accurately the characteristics of an induction motor, no load and blocked rotor tests were made and the diagrams drawn. For a motor of the Boucherot type,the peculiar features inherent to it should give for the different sets of windings diagrams as shown in Fig.12. As the outer winding has the smaller inductance,the diameter of the circle representing it should be the larger. Since the inductances for the two windings together,are in parallel,the diameter of the circle representing themshould be approximately an average of the diameters of the circles for the inner and outer windings alone. Again,however,the actual motor seems to be at fault. The diagrams for the inner and outer windings were reversed

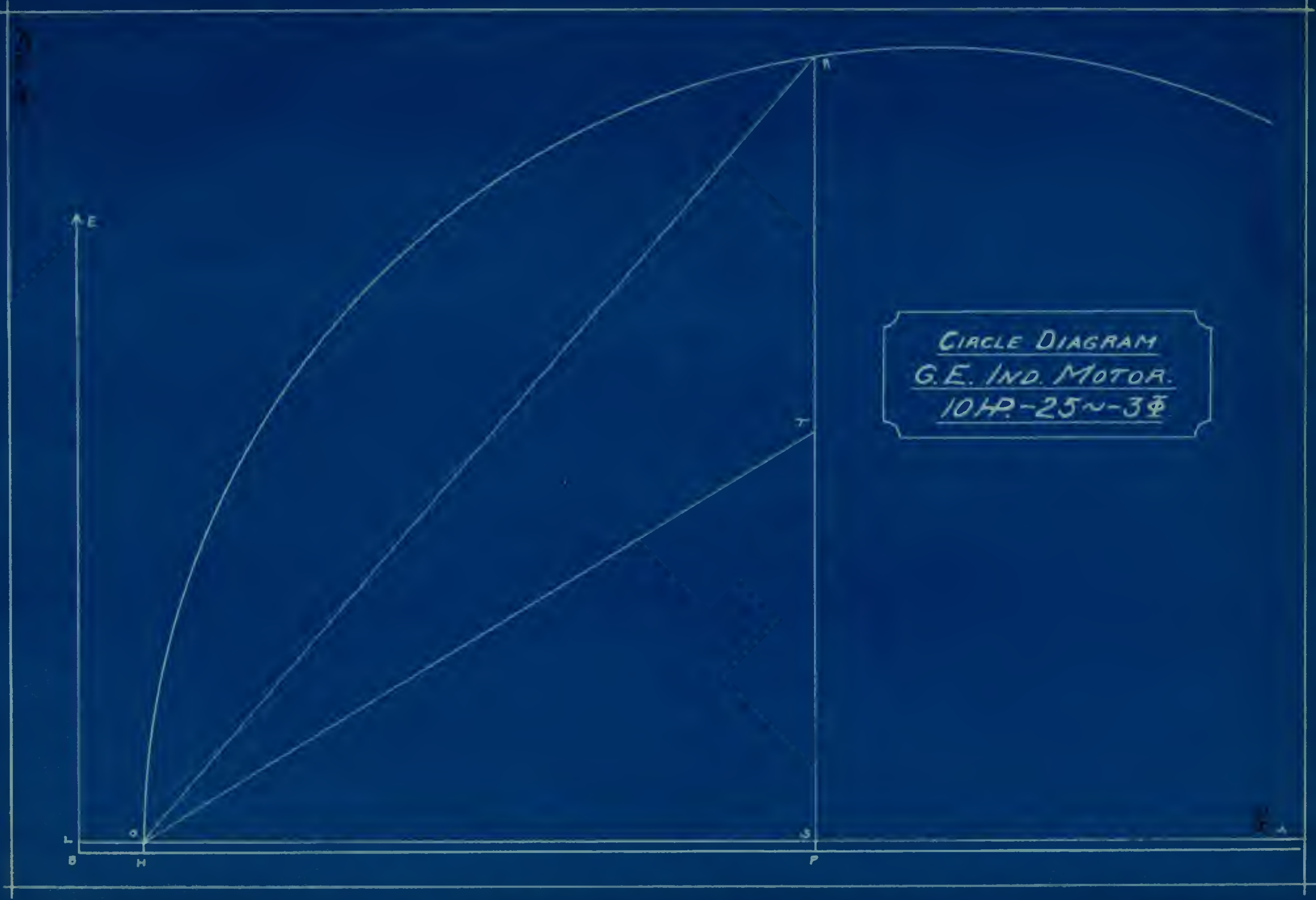
PL. 12

CALCULATED CIRCLE DIAGRAMS
BOUCHEROT IND. MOTOR.





CIRCLE DIAGRAMS
BOUCHEROT IND. MOTOR.



CIRCLE DIAGRAM
G.E. IND. MOTOR.
10 HP. -25~-3Φ

so that,as far as they show,just opposite results as were desired were obtained. The diagram for the two windings together is very small when compared with that drawn for the G.E.motor. This is further evidence of comparatively large inductance. On the other hand the no load current,and especially the wattless component,is smaller for the Boucherot motor than for the G.E. The higher resistance of the Boucherot motor would account for it. This somewhat high wattless no load current in the G.E.motor explains to an extent the fact that its power factor is lower than that for the inner winding of the Boucherot motor at the same output. The G.E. motor also shows its excellent design in that the copper losses in both the rotor and stator,as indicated by RT and TS,respectively,are about equal. The Boucherot motor,however,shows that the rotor copper loss is about twice that of the stator.

CONCLUSIONS.

The results of this test on the Boucherot motor do not show many of the excellent qualities claimed for a motor of this type. As most of the departures from theoretical conditions were explained by the over-amount of resistance in each set of rotor bars,an apparent explanation of its cause would not be amiss. There is no doubt but that the winding is of great enough cross-section for this had been carefully figured out by the designers,and by inspection appears to be greater than that of the G.E. winding. The only other source of resistance is that of contact. Fig.2. shows the method of attaching the rotor bars to the end rings. Since the bars fitted somewhat tightly in the rotor slots,it was necessary,in order to place the rings on the rods,to make the holes in the end rings slightly larger than the diameter of the rods. Accordingly there was considerable contact resistance introduced where but little should have been present. In the case of the outer rods the evil was augmented,for the shoulder shown on the inner rods was lacking on the outer ones,and so the resistance was still greater. This seems to be a solution of many of the discrepancies present and could be remedied,as is done in most cases,by soldering the con-

nections. It was proposed that this be done but lack of time prevented.

Another reason for the differences noted might be explained by the fact that when the motor is started up from rest to full speed the current is shifting constantly from one winding to another. Accordingly for a certain speed one winding might carry two-thirds of the rotor current while the other carried one-third and for some other speed the divisionof current would be different. Therefore when an attempt is made to analyze the conditions by testing one winding and then the other and finally the two together,it becomes difficult to make the results check up,since the currents in the first cases are constrained to follow the paths in the single windings.

This is especially noted in the case of the torque-slip curves. While the total torque is the sum of the torques supplied by each winding,it does not follow that when the two windings are on the rotor that the resultant torque,for any definite speed,is the sum of the torques supplied at that speed by each winding when tested alone. For while one winding at a certain speed might carry a heavy current,when used in conjunc-

tion with another winding,the current in it might be nearly zero. It is therefore difficult to determine what is actually occurring in each set of windings when the two are used together,or to test them separately and say what they will do when operated together. The best method is to test the motor under working conditions and thus see if it fulfills the functions for which it was designed.